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INTERNATIONAL DRILLING & PRODUCING

- Developing Japan's Dissolved Gas
- IPR Curves For Well Behavior
- How To Estimate Oil Reserves
- Drilling Seminars In Red China
- Cooper Basin Status Report

ABOUT THE COVER: The Dullingari North No. 1 is shown being drilled for Delhi International Oil Co. in South Australia, some 8 miles west of the Queensland Border. An oil discovery, the well is shut-in pending completion of a pipeline. For a review of Cooper Basin activity, see page 48.

NEXT MONTH: The July issue will concentrate on downhole tools and technology, with a look at pumpdown tools, wellbore hydrostatics, well servicing experience, and tubing failure.

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Seismic crew working for Shell Oil Co. in the Egyptian desert.

work in Argentina, and contracts have been approved for four additional international crews to operate in the Neuquen and Santa Cruz oil basins in the west and south of Argentina. Meanwhile, drillers are scheduled to spud more than 900 wells in Argentina this year, an increase of more than 200 over 1979's total.

Africa also is among the leaders in seismic activity, and it also boasts more than 200 active drilling rigs, with more on the way. Cameroon, for example, increased its rig count to 7 during the past year, and plans a period of stepped-up oil production and exports. Forecast to reach 22 to 26 million bbl by 1982, Cameroon production could reach 38 million bbl by 1983-84, with a possible doubling by the end of the decade. Most of this optimistic forecasting is based on recent oil finds offshore Cameroon, and they are prompting additional exploration in the shallow waters along the coast of West Africa by such nearby countries as Gabon and Nigeria.

Oil companies operating in U.K. waters of northwestern Europe still are waiting for results of the 7th round of licensing that finally got underway last month. Meanwhile, a good deal of attention is directed at waters some 300 miles off the west coast of Scotland. That's where the British National Oil Corp., the U.K. Department of Energy, and a group of 14 private companies will test deep waters of the North Rockall Trough.

Although limited to only one well, the project could lead to additional wells in other little-explored areas of the U.K. continental shelf, according to the Energy Department, which is of the opinion that deepwater areas of the shelf could contain oil reserves in the region of 4 billion to 7 billion bbl. The well on the Rockall Trough will be a deep one, with TD between 15,000 and 20,000 ft.

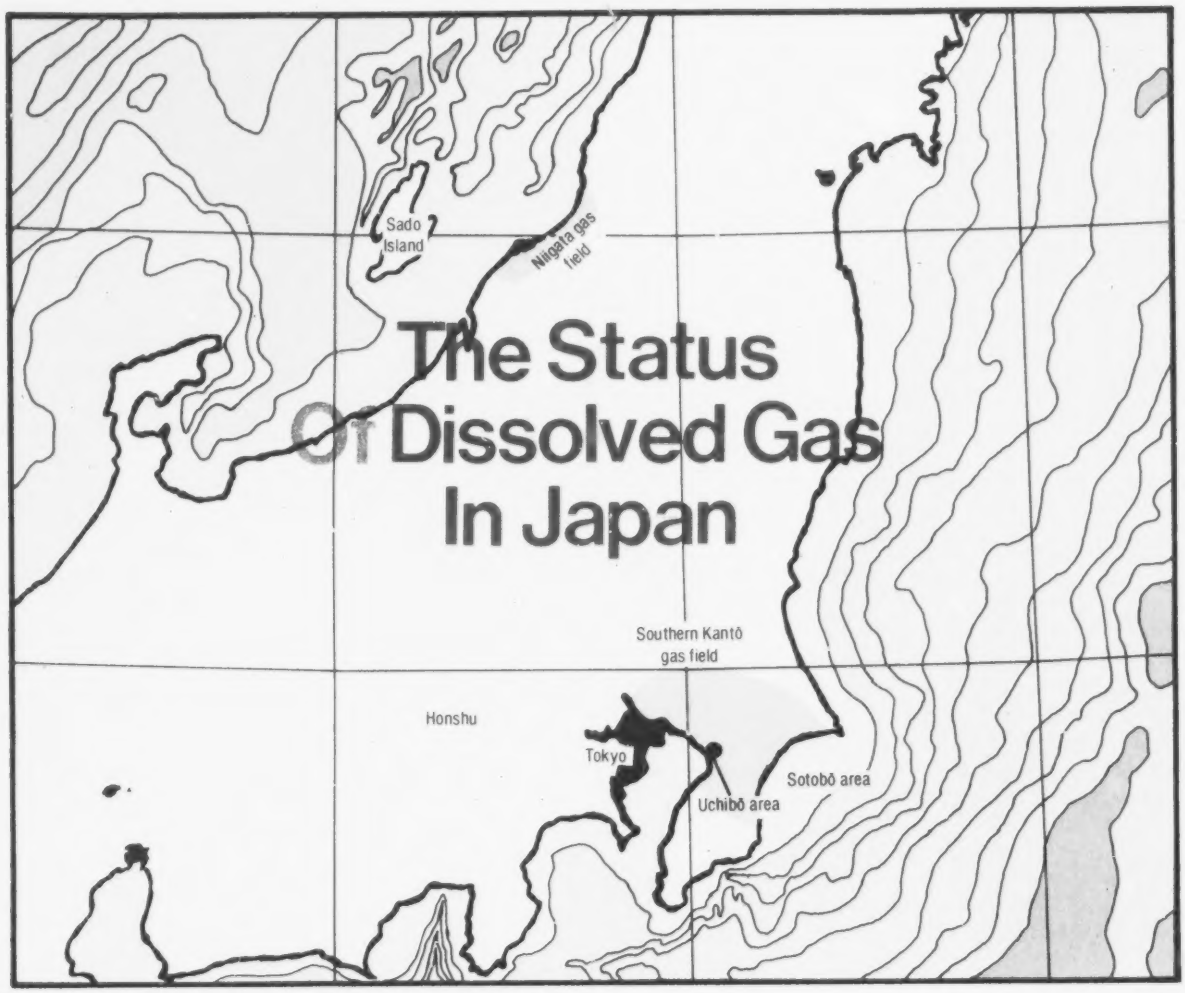
In more conventional North Sea action, meanwhile, Marathon Oil Co. earlier this year made what it calls a "potentially significant" oil and gas find near the Brae field, 150 miles off Scotland's east coast. Marathon's well, in 370 ft of water in block 16-3A, tested 15,000 b/d of oil from approximately 15,400 ft.

In the North Sea's Norwegian sector, anticipated activity north of the 62nd parallel received a jolt this spring when the accommodation rig Alexander Kielland tipped over at the Ekofisk Complex. Already edgy about what oil drilling operations might do to the ecology of the Norwegian Sea, the Norwegian Storting (Parliament) was not reassured by the accident. It is, therefore, taking another look at the exploration program that would have permitted spudding of up to six wells in two selected zones north of the 62nd Parallel this summer.

We promised to try to keep politics to a minimum in this article, but obviously didn't succeed very well. Probably it's something that shouldn't even be attempted because politics and energy have become hopelessly entangled during the past 6 or 7 years. There's no room in this article for a discussion about where this trend will take us, but it is interesting to watch where it is taking the Soviet Union. According to a recent analysis by Aleksandr P. Krylov of the Soviet Academy of Sciences, Russia's oil production will soon begin to decline unless its government-directed system of drilling and exploiting deposits is changed. He says drillers should move their rigs out of existing fields and look for new ones elsewhere.

Soviet central planners, Krylov points out, set drilling targets only in terms of thousands of meters to be drilled, so oil producers simply direct the drillers to send down more and more holes into existing deposits.

China is another area worth watching, but not for the same reason. That country has been studying the terms and conditions of offshore lease contracts offered by countries around the world with an eye toward using the best portions for the concessions China is expected to offer later this year. What they come up with could be a classic of its kind. ■



The Status Of Dissolved Gas In Japan

Fig. 1. Location of Niigata and Southern Kantō gas fields.

by Prof. S. S. Marsden, *Stanford University, Stanford, Calif.*

Suiyōseiten'nen gasu, a major Japanese hydrocarbon resource, is natural gas found dissolved in subsurface brines rather than dissolved in crude oil or as free gas. Because it is primarily methane and contains essentially no hydrogen sulfide, it is in considerable demand for use both as a town gas or domestic fuel and as a feed-stock for the chemical industry. Since the late Professor Kōzō Kawai and I published a paper on this Japanese gas field 14 years ago,[1] others have expressed interest in the field and have found this material elsewhere in the world.

This article describes developments in Japan during the past 14 years. A brief review of the subject will be presented for the casual reader, but those interested in more detail may refer to the original paper and its references. After this review, a description of the current situation will be made, based on recent field trips to two major producing areas – the Mobara field of the Chiba Prefecture east of Tokyo, and the Niigata field of the Niigata Prefecture of northwestern Japan (Fig. 1).

Suiyōseiten'nen Gasu

Because the solubility of methane in water or brine is low relative to its solubility in oil, the amount of gas per unit reservoir volume is also relatively low. This solubility increases with pressure and hence with reservoir depth. The reservoirs are typically at 500 to 1,000 meters and at no more than 2,000 meters, which puts an upper limit on the gas content per unit pore volume. It is much less than that from oil reservoirs.

Reservoir rocks and producing gas-water ratio (GWR) are the main features controlling development of the fields. Cores are extremely difficult and expensive to take, so accurate values of porosity and permeability are often not known. The former is believed to be 20 to 30%.

In the Niigata area, reservoir rocks are highly

permeable sands and gravels separated by mudstones. Electric logs (Fig. 2) are used to identify the reservoir rocks, which have thicknesses of 20 to 40 meters. A single-zone completion usually is used. Estimated value of productivity index for water ranges from 2,000 to 4,000 kl/d/kg/cm² (kl = kiloliter).

Reservoirs are typically synclines. Wells located along the axis are more prolific and have higher GWR's than those on the flanks. Producing GWR is about what would be calculated from the reservoir depth (Table 1); this is known as the ordinary type reservoir. There is an infrequent indication of free gas.

In the Chiba Prefecture, reservoir rocks are poorly consolidated sandstones and siltstones. In the Uchibō area (the western part of the Chiba Prefecture), permeability to water is about 200 md, while in the Sotobō area (the eastern part of the Chiba Prefecture), it is about 70 md (Fig. 1). These values are much less than those for the Niigata area. In the Chiba Prefecture, multizone completion with a screened liner a few hundred meters long is often used. The reservoirs in the Uchibō area are of the ordinary type described earlier. In the Sotobō area, the deeper zones are ordinary, but shallower zones belong to the Mobara type found near the city of Mobara in the Chiba Prefecture. The producing GWR in a Mobara-type reservoir has an initial value of 3 m³/kl or more and increases with production (see Fig. 2 of Reference 1). Sometimes wells flow spontaneously, and the GWR goes as high as 20 m³/kl. The type of reservoir affects the development system as well as environmental regulations.

Chiba Prefecture

There are 12 producing companies in the Chiba Prefecture. Production by one of the larger of the companies near Mobara averaged 16 MMcfd (454,000 m³/d) in 1977. It operates 17 fields in the Sotobō area and 3 in the Uchibō area.

A 1949 study by the Geological Survey of Japan and the University of Tokyo showed tnat this gas existed everywhere over a large area in the Chiba Prefecture and neighboring prefectures (see Fig. 3 of Reference 1); thus, it was only necessary to get a lease from the government to develop new areas. Usual procedure is to drill an exploration well and test it for 1 or 2 months. If the GWR is greater than 3 m³/kl at a depth of less than 1,000 meters, then another Mobara-type field is indicated.

The production of dissolved gas in the Southern Kanto gas region (see Fig. 3 of Reference 1) reached a peak of 20.6 billion cu ft/year (585x10⁶ m³/year) in 1970, and declined somewhat to 16 billion cu ft/year (454x10⁶ m³/year) in 1977.

In 1970, the Government of Japan and the Chiba Prefecture introduced three regulations to cut down on land subsidence. First, production was prohibited from the eastern part of the city of Tokyo and the western part of the Chiba Prefecture, where there was an epicenter of land subsidence. Second, water production from the area was controlled by reducing it stepwise. For example, around the city of Chiba

TABLE 1. Producing GWR for ordinary type gas reservoir in the Niigata Prefecture

Depth, meters	GWR, m³/kl
100	0.35
200	0.60
300	0.84
400	1.05
500	1.25
600	1.40
700	1.55
800	1.70
900	1.80
1,000	1.95

over a period of 3 years – from 1971 to 1973 – it was decreased to a total of 50% of what it had been before and, at present, all of the produced water is reinjected. Third, the abandonment of wells having a spacing of less than 1,000 meters for the ordinary type and less than 250 meters for the Mobara type was required.

Annual surface surveys for subsidence are made by both the company and the prefecture. Surveys of reservoir pressure are made at least annually by the company and reported to the prefecture.

Average price for the gas in Japan when sold for town gas is about $4.25/Mcf and two-thirds of this when sold for chemical manufacture.

Recovery of iodine from this rather unusual brine is a major source of income for the natural gas companies – typically, about 16%.

Excess produced water which is not reinjected or used to recover iodine is run into the Pacific Ocean.

Drilling plus casing costs are $18.3/ft. Fishtail bits are used successfully in the soft rock. Closed systems and PVC casing and tubing are used to prevent corrosion and scaling.

While the tubing flow gas lift system was formerly used with 4-in. casing and 2-in. tubing, the tendency now is for a casing-flow gas lift with 3-in. casing and ¾ to 1-in. gas-injection pipes. This gas-lift system cuts down on operation costs. By using 80-mesh stainless steel screen, sand production is usually not a problem. Sometimes two layers of screen (80-mesh for both layers, or the outer one of 30-mesh and the inner one of 80-mesh) are used. Gravel packing has been tried with one layer of 80-mesh screen, but was considered unnecessary and too expensive.

Because of their importance, more should be said about the characteristics of the Mobara-type reservoirs. The two Pliocene formations of the Chiba Prefecture which produce this kind of reservoir are the Umegase and Ōtadai, which have maximum thicknesses of 370 and 270 meters, respectively. They are interbedded every meter or so by thin mudstone layers – important because they impede upward migration of gas.

A core from these thin mudstones releases gas when it is brought to the surface. This contributes to the high GWR of the Mobara-type reservoir. To get the gas to migrate from the mudstones to sandstones, which is a slow process, a large pressure drop is needed. The low sandstone permeability of 70 md or less and the presence of many faults, which hinder or prevent natural water drive, produce a pressure de-

TABLE 2. Field test conditions in Niigata

	Initial condition as of Oct. 1971	Condition as of Apr. 1976
Location A		
Surface separation system:		
1. Production, G6 zone		
Injection, G5-1 zone		
Water production	3,000 kl/d	2,800 kl/d
Gas production	5,000 m^3/d	4,600 m^3/d
Producing GWR	1.7 m^3/kl	1.6 m^3/kl
2. Production, G4-1 zone		
Injection, G5 zone		
Water production	2,500 kl/d	2,900 kl/d
Gas production	3,000 m^3/d	1,200 m^3/d
Producing GWR	1.2 m^3/kl	0.4 m^3/kl
Location B		
Subsurface separation system:		
1. Production, G5-1 zone		
Injection, G6 zone		
Water production	3,000 kl/d	2,800 kl/d
Gas production	4,700 m^3/d	3,600 m^3/d
Producing GWR	1.6 m^3/kl	1.3 m^3/kl
2. Production, G5 zone		
Injection, G4-1 zone		
Water production	2,500 kl/d	2,900 kl/d
Gas production	3,500 m^3/d	3,100 m^3/d
Producing GWR	1.4 m^3/kl	1.1 m^3/kl

Source: Niigata branch of the Natural Gas Producers' Association

TABLE 3. Geological properties of test zones in Niigata

	Upper depth of test zone, meters	Net pay thickness, meters	Lithology
G 4-1	590	24	Small gravel, 13 meters Coarse sand, 11 meters
G 5	680	23	Small gravel, 9 meters Coarse sand, 14 meters
G 5-1	740	36	Small gravel, 4 meters Coarse sand, 32 meters
G 6	920	36	Small gravel, 15 meters Coarse sand, 21 meters

Source: Niigata Branch of the Natural Gas Producers' Association

cline as great as 15 kg/cm^2 in 1 or 2 years after start of production (see Fig. 2 of Reference 1). The same pressure drop makes for a greater expansion of gas in shallower zones than that in deeper zones, thereby giving a higher gas saturation and higher gas relative permeability in shallower zones. The completion interval is usually a few hundred meters of alternating thin sandstones and mudstones, which increases transfer areas between layers and makes it easier for gas to flow into the sandstones. The Mobara-type performance is observed at depths less than 1,000 meters.

Productivity and injectivity of a Mobara-type reservoir are usually about the same, but the latter is occasionally greater than the former, possibly because of water collecting in the gas cap formed during production. For the ordinary reservoirs, injectivity is usually one-half the productivity, possibly from plugging by unfiltered water. Initial water permeability for the ordinary-type reservoir is about 200 md, whereas that for the Mobara-type is about 70 md; but

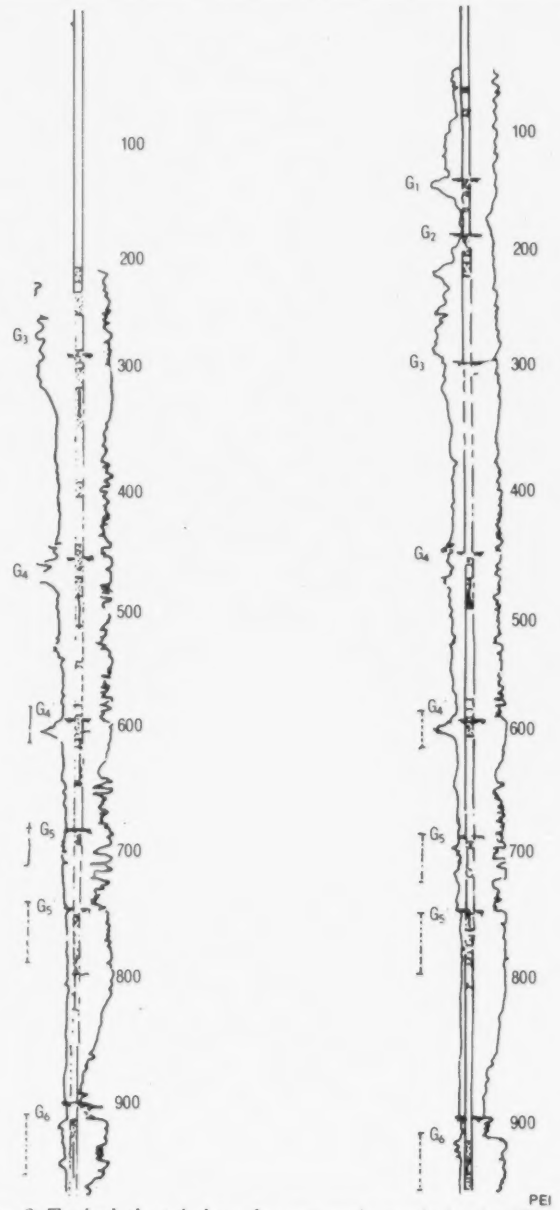


Fig. 2. Typical electric logs for reservoir sands in the Niigata area.

the effective permeability decreases to 20 or 30 md with the GWR increasing to 15 to 20 m^3/kl.

Total reserves of the Southern Kantō gas region of the Chiba Prefecture and neighboring prefectures are an estimated 17 tcf (5×10^{11} m^3).

Niigata Prefecture

Until the late 1950s, this dissolved gas was the major type of natural gas produced in the Niigata Prefecture, but dry gas reservoirs became the major source of gas after discoveries in 1960 and later. The production rate of dry gas jumped by four times – from 18.6 billion cu ft/year (527×10^6 m^3/year) in 1965 to 77.4 billion cu ft/year ($2{,}190 \times 10^6$ m^3/year) in 1977 – but the production rate dropped one-half, from 5

TABLE 4. Suiyōseiten'nen gasu reserves in Japan

District, field	Areal extent, km²	Pay thickness, m³/kl	Initial GWR, m/kl	Gas in place, $10^6 m^3$ Porosity 25%	Porosity 30%	Status
Hokkaido						
Ishikari	390	40	1/4-1/8	613	736	Possible
Oshamanbe	40	47	0.2-1.5	310	372	Production, 2 zones
Tohoku						
Aomori	18	30	0.3	34	41	Possible
Kisagata	14	60	0.65	137	164	Production
Sakata	45	40	0.3	135	162	Possible
Yamagata	81	65	1/4-1/2	441	529	Abandoned
Kantō						
Southern Kantō				551,000	661,000	Production
Sotobō	1,030	345-665	1.3-2.9	245,000	293,000	
Uchibō	945	205-510	1.3-2.0	166,000	199,000	
Others	1,750	70-400	0.5-2.0	113,000	136,000	
Tokyo	235	80	1.5	7,000	8,000	
Kawasaki	140	500	1.1	19,000	23,000	
Others	360	180	1.2	19,000	23,000	Possible
Chubu						
Ogasa	200	200	1.5	15,000	18,000	Possible
Suwako	20	75	1/3	125	150	Production
Niigata				88,000	105,000	
Nishikanbara -Uchino	140	320	1.0-2.5	19,000	23,000	Production, 7 zones
Niigata	85	260	0.7-2.5	8,000	10,000	Production, 5 zones
Matuhama	70	195	0.6-2.5	5,000	7,000	Production, 4 zones
Nagaoka	40	100	2.5-3.0	3,000	3,000	Production, 2 zones
Nakajo	25	546	0.6-2.4	5,000	6,000	Production, 11 zones
Others	355	100-546	0.6-2.5	46,000	56,000	Probable and possible
Shisui	12	110	0.3	99	119	Production
Kahokugata	50	40	1/4	125	150	Possible
Kinki and Chugoku						
Ōsaka	450	32	0.1	360	432	Possible
Hinokawa	8	32	1/4-1/2	11	13	Possible
Kyushu						
Turusaki	12.5	70	0.3	66	79	Possible
Kakuto	8	28	1/4	14	17	Possible
Miyazaki	400	480	1.0-2.0	28,000	38,000	Production, 3 zones
Nichinan	30	100	1.5	1,000	1,000	Possible
Okinawa						
Okinawa-jima nambu	300	260	1.7	29,000	35,000	Suspension, 2 zones
Miyako-jima	150	100	1.5	6,000	7,000	Possible
TOTAL				739,000	887,000	

Source: Geological survey in Japan, 1975

billion cu ft/year (141×10^6 m³/year) in 1965 to 2.6 billion cu ft/year (74×10^6 m³/year) in 1977. This reduction was attributed to efforts to cut down on land subsidence by limiting water production.

Subsidence in Niigata city became significant by 1958. Since that time, production is no longer allowed from wells within the city of Niigata, and brine from those in a nearby surrounding belt must be reinjected. Reserves of dissolved gas in Niigata are large, so rational utilization of this gas is important to the local economy.

To develop a system for producing dissolved gas without subsidence, field tests have been carried out since 1965 under the supervision of the prefecture. Full-scale field tests of two different systems have been carried out in a suburb of Niigata city since October 1971. These tests were originally planned to extend for 2 years, but results were promising; thus, tests are being continued. There are 11 companies taking part in these tests, under supervision of the prefecture and the Niigata Branch of the Natural Gas Producers' Association.

In these tests, two different closed systems of gas separation and water reinjection are used to compare technical performance and costs. One uses a surface separator and the other a subsurface separator. The two locations for the test wells are separated by 700 meters. At each location, two production wells and two injection wells are used, with one production-injection system completed in a shallower zone; the other in a deeper zone (Tables 2 and 3).

Because the chloride ion, Cl^-, concentration is different in each formation, it is used as a tracer to determine water movement. A change in Cl^- concentration and decrease in GWR are used as indicators of reinjection water breakthrough. This took place in

1½ to 2 years in the thin layers, but in a thicker, more uniform sand, breakthrough has not taken place in 5 years.

The GWR in one thin zone decreased from 1.2 to 0.4 m^3/kl in 5 years by water recycling. Although a GWR of 0.5 m^3/kl is usually considered the economic cutoff point, a lower one is allowed for the test.

Because foam can be a problem, small amounts of silicone anti-foamers are continuously injected into the separators. Closed systems for water treatment are used to prevent corrosion and also precipitation of clogging materials from the brine, so there is no serious problem in water injection.

When brine is used to recover iodine in the usual operation and it is treated in the open system, injection wells must be washed out twice a month to clean the liner or the formation around the well bore.

Results of these tests to date show that:

- There have been no appreciable effects of the test operation on the observation wells. There is no evidence of lowering of water level or increase in the compaction of layers.
- Although the pressure of the gas zones is raised considerably by reinjection of water in the nearby production area, the injection capacity of test wells declines very little. It is expected that it will be easy to inject water in the future.
- Data obtained so far indicates that minimum well spacing should be approximately 1,000 meters.
- The actual operation time has been about 90% of the total period of the test. This or a higher level is expected in the future.
- Material selection and corrosion-prevention techniques have been satisfactory.
- Average cost of gas production from Nov. 24, 1971, to Mar. 31, 1975 was approximately $2.27/Mcf. The future cost of gas, however, will depend upon the inflation rate.

Other Fields

Although most of the dissolved gas is produced in the two areas described, it is still found in smaller quantities in many other areas of Japan, ranging from Hokkaido to Kyushu and even in Okinawa.

Table 4 was taken from data presented by the Geological Society of Japan.[2] The estimates of area and thickness are for many fields whose gas is being used locally. The GWR's are those of initial production, and are shown either in decimal form or in fractional form, according to the original source of information.

TABLE 5. Japanese natural gas production, 1977, 1,000 m^3

Prefecture	Types of reservoir: Suiyōsei gas	Oilfield gas	Wet free gas	Coal mine gas	Total	% of 1976	% of total
Hokkaido	720	–	2,780	–	3,500	92.0	0.12
Akita	7,920	17,680	2,370	–	27,960	90.2	1.00
Yamagata	–	7,900	–	–	7,900	105.7	0.28
Fukushima	–	–	–	5,300	5,300	160.1	0.19
Ibaragi	–	–	–	3,180	3,180	96.0	0.11
Niigata	74,120	26,470	2,193,230	–	2,293,820	117.2	81.80
Nagano	260	–	30	–	290	102.8	0.01
Chiba	454,350	–	–	–	454,350	94.8	16.20
Tokyo	200	–	–	–	200	100.0	0.01
Shizuoka	10	–	–	–	10	36.0	–
Toyama	810	–	–	–	810	92.4	0.03
Mie	–	–	–	–	–	–	–
Miyazaki	6,740	–	–	–	6,740	116.0	0.24
TOTAL:	545,130	52,050	2,198,410	8,480	2,804,060	112.5	100.00
% of total:	19.44	1.86	78.40	0.30	100.00		
% of 1976 production:	95.09	101.27	118.07	128.04	112.47		

TABLE 6. Uses of Japanese domestic natural gas production, 1977, 1,000 m^3

Prefecture	Chemical industry	Other Manufacturers	Electrical generation	Town gas	Service for Industry	Others	Total
Hokkaido	–	–	–	1,030	30	–	1,070
Akita	440	340	–	25,120	30	–	25,940
Yamagata	–	–	–	7,710	–	–	7,710
Fukushima	910	–	–	4,390	–	–	5,300
Ibaragi	3,180	–	–	–	–	–	3,180
Niigata	750,871	306,680	707,600	475,840	210	80	2,241,280
Nagano	30	3	–	260	3	–	290
Chiba	274,150	6,360	–	156,740	132	220	437,610
Tokyo	–	–	–	–	30	–	30
Shizuoka	–	–	–	10	–	–	10
Toyama	–	–	–	770	–	–	770
Mie	–	–	–	–	–	–	–
Miyazaki	–	840	–	1,290	332	710	3,170
TOTAL:	**1,029,580**	**314,220**	**707,600**	**673,170**	**780**	**1,010**	**2,726,360**
% of total:	37.76	11.53	25.95	24.69	0.03	0.04	100.00
% change from 1976:	94.71	89.13	213.92	103.13	151.84	74.41	112.43

Because porosity is not always known, estimates of gas originally in place are calculated from porosities of 25 and 30%. If a recovery factor of 50% is used, ultimate reserves are about 13 tcf (370×10^9 m^3). At the end of 1974, 400 billion cu ft (11×10^9 m^3) had been recovered.

Production of natural gas of different kinds is shown in Table 5, and its uses in Table 6. Dissolved gas ranks second to ordinary dry gas, but is far greater than oilfield and coal mine gas. The production of this gas decreased about 5% from 1976 to 1977, basically because of environmental regulations. Table 6 shows the slight decrease in chemical industry use of gas and the slight increase in town gas use. The marked increase in use for electrical generation is curious, but may be due to a matter of distribution systems. ■

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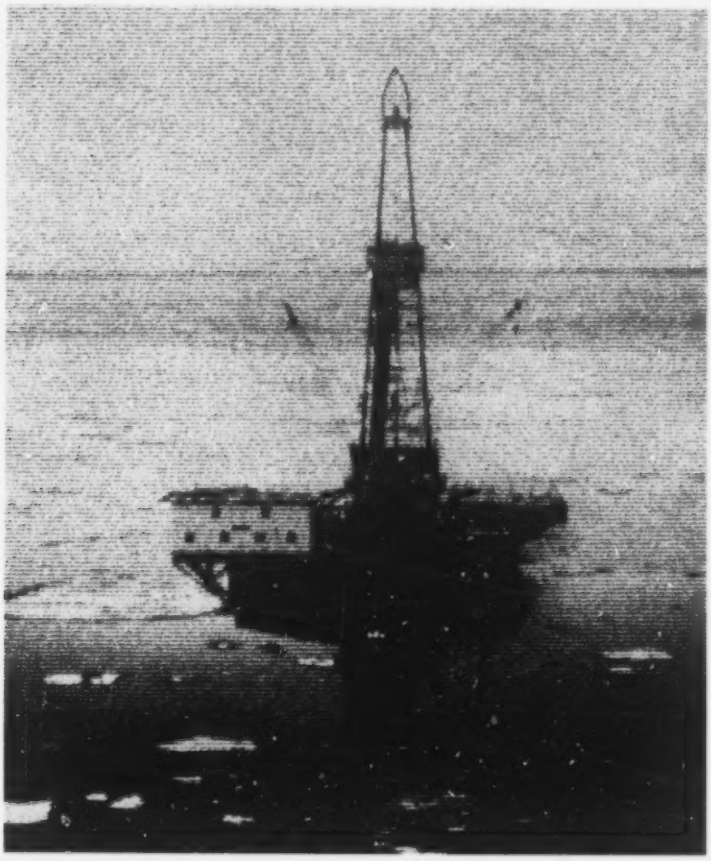
About the Author

Dr. Sullivan S. Marsden holds a BA degree in engineering chemistry and a PhD in physcial chemistry, both from Stanford University. On completing his doctorate, he was named assistant director for the National Chemical Laboratory of India at Poona, India, then returned to the U.S. as associate professor of petroleum engineering at Pennsylvania State University. After 4 years, he returned to Stanford and advanced to full professorship in 1963.

He has been a visiting professor at the University of Tokyo and at Abadan Institute of Technology, Abadan, Iran. His short course lecture history includes appearances at universities and institutes in Mexico, Angola, Taiwan, Japan, Venezuela, and Russia.

He is the author of more than 70 technical papers and holds two patents on work done at Stanford.



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